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MEMORANDUM REPORT

M61-29-1

THREADED FASTENERS LOCKING DEVICES
EVALUATION OF LOCTITE SEALANT

by

S. M. Kalan

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PHILADELPHIA 37, PA

Frankford Arsenal
Philadelphia 37, Pa.

Memorandum Report M61-29-1
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THREADED FASTENERS LOCKING DEVICES
EVALUATION OF LOCTITE SEALANT

Prepared by: S M Kalan
S. M. KALAN
Chief
Materials Engineering Section

Reviewed by: R D France
R. D. FRANCE
Chief
Basic Materials Evaluation Branch

Approved by: L H Adams for
J. J. CUMMINGS
Chief
Engineering Support Division

OBJECT

To evaluate the efficiency of LOCTITE Sealant as a fastening method for the prevention of loosening of threaded fasteners due to shock and vibration. As a result of this investigation, it is desired to obtain data necessary for the preparation of a specification for this material if found to have the desired properties.

SUMMARY

LOCTITE Sealant Compound was investigated for its ability as a screw locking material to prevent threaded fasteners from loosening under shock and vibration environments. Three grades of LOCTITE, having shear strengths of 75(H), 300(E), and 750(C)psi, were evaluated. Under the worst condition - alternate shock (1500 G) and elliptic vibration (4 G at 5 to 45 cps) - the weakest grade was as effective in preventing "walkout" as nylon insert screws, and "dab" materials, MIL-V-173 varnish and MIL-S-11031 sealing compound. A subsequent mathematical analysis showed that the test vibration conditions were very mild with effective developed torques of considerably less than 0.5 inch pound. It is recommended that the investigation be continued to verify this analysis which indicates that the design of a quantitative test is feasible and desirable.

LOCTITE Sealant compounds should not be relied upon for fastening under high frequency, high amplitude vibration conditions. LOCTITE Grades A, C, and H are adequately covered by Military Specification MIL-S-40083(ORD) although a vibration performance test requirement would be desirable. Application after fastener insertion is undesirable since extent of penetrability is unpredictable.

AUTHORIZATION

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INTRODUCTION

In the operation of military equipment, malfunctioning has been caused by loosening of threaded fasteners under vibration and shock environment. These threaded fasteners may be of the headed type for joining parts or the headless type for adjustment purposes.

Mechanical methods such as lock washers, cotter pins, staking, etc. do not completely prevent "walkout", complicate the design unnecessarily or are impossible to use.

Frankford Arsenal conducted several investigations[1, 2, 3*] to develop a universal locking system with a locking compound which could be applied by "dab" or other similar means to the screw-plate junction of the assembly. The objective was to prevent motion of the screw during shock and vibration and yet allow disassembly to be easily accomplished without damage to it. Under the test conditions used, only Paraphenyl phenol Formaldehyde Varnish, MIL-V-173 and Sealing Compound, MIL-S-11031 materials met the requirements. Nylon insert fasteners were also found to perform as well as these materials.

However, the use of these "dab" type materials imposed several undesirable processing techniques and the search for materials with wider application tolerance has been continuous.

In recent years LOCTITE Sealant has been proposed as a material which may have the desirable characteristics without the complications.

This investigation was undertaken to evaluate the claims made by the manufacturer and the ability of LOCTITE to meet the antivibration shock loosening requirements for military materiel.

DESCRIPTION OF MATERIAL[4, 5]

LOCTITE Sealants are modified polyester materials in fluid form supplied in various viscosities and colors in polyethylene squeeze dispensing bottles (fig. 1) and are designed for a number of developed shear strengths after curing. (See Table I.)

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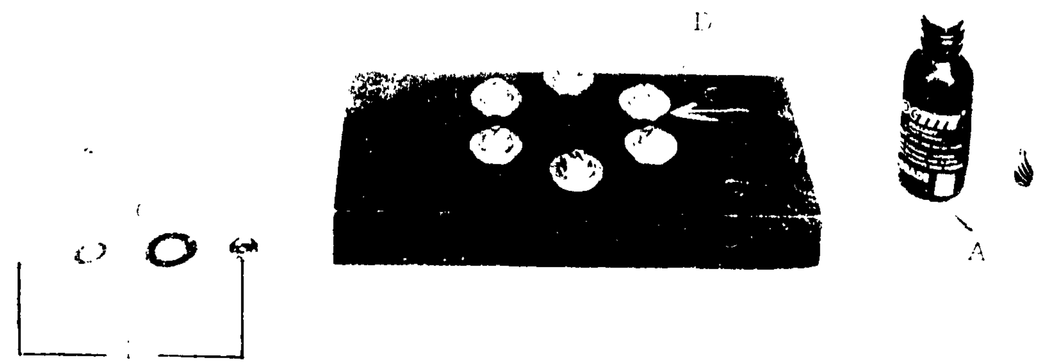
*See Bibliography references.



A - Polyethylene Squeeze Bottle
B - Exploded View of Screw Assembly
C - Screw Assembly
D - Metal Plate

Figure 1. View of Screw Assembly, Screw Assembly Disassembled, Plate with Six Screw Assemblies and Applicator Top Bottle of LOCTITE "H"

Table I. LOCTITE SEALANTS

Grade	Identifying Color	Viscosity (cps)	Shear Strength (psi)
A	Red	10-15	750-1000
D	Orange	40-50	750-1000
AV	Red	100-150	750-1000
B	Yellow	20-30	525-700
C	Blue	10-15	300-400
CV	Blue	100-150	300-400
E	Purple	10-15	150-200
EV	Purple	100-150	150-200
H	Brown	10-15	75-100
HV	Brown	100-150	75-100

LOCTITE will polymerize in contact with metal in the absence of air to a tough, heat and fungi resistant adhesive solid compound. The supplier recommends the use of the low viscosity material for clearances less than 0.005" and the high viscosity material for clearances of 0.004" to 0.010".

Good bonds can be obtained only with clean surfaces free from grease and oil. The supplier states that inert surfaces such as zinc or cadmium may require activating with a degreasing solution containing 5% Locquic Activator in order to obtain proper bonding. LOCTITE will develop 50% of its full strength within 6 hours at 75° F or 90% within 12 hours at this temperature. The full cure time can be reduced to 10 minutes by exposure to a temperature of 212° F.

TEST PROCEDURES AND RESULTS

In spite of the numerous difficulties caused by loosening (walkout) of threaded fasteners, there appears to be very little in the literature to adequately relate the vibration and shock forces with this effect.

A number of empirical test methods have been used to evaluate preventive measures designed to overcome this behavior.[1, 2, 3, 6, 7] However, these are not quantitative or subject to standardization.

In the work that was previously done at Frankford Arsenal, screws could be made to "walkout" under vibration only with the introduction of high shock impulses imposed during the test.

Three test procedures were evolved during the course of this investigation in an attempt to yield a reproducible condition severe enough to cause loosening. The only machine available for this investigation was a LAB 200 vibrator. The machine is capable of simultaneous vibration in two directions, vertical and horizontal, with a maximum double amplitude of 0.25" over a frequency range of 5 to 60 cps.

The test specimens consisted of twelve 3" x 6" x 3/4" metal plates (fig. 1) prepared as follows:

1. Metals

a. Two plates - 7075 aluminum alloy.

b. Two plates - 7075 aluminum alloy with black anodize treatment MIL-STD-171, Finish 7.2.2.

c. Two plates - 1020 steel.

d. Two plates - 1020 steel with cadmium plate treatment, MIL-STD-171, Finish 1.1.1.2.

e. Two plates - 85-5-5-5 copper alloy.

f. Two plates - 85-5-5-5 copper alloy with black oxide treatment MIL-STD-171, Finish 3.2.

Note: All treatments were done after all machining was completed.

2. Machining

Six evenly spaced holes were drilled and tapped on the circumference of a two-inch diameter circle in each plate. In order to avoid the effects of burrs and other "hold up" variables of the tapped threads, the machining procedures of the previous investigations[1] were used. These are described below.

Step 1 - Drill 11/64 inch hole completely through the plate

Step 2 - Tap with #10-32 American Standard machine tap

Step 3 - Ream with #15 drill

Step 4 - Clean in degreasing solution

3. Machine Screws

No. 10-32 class 2 American Standard fillister head machine screws, 3/4 inch long (fig. 1) were used in all tests. Since the purpose was to evaluate the locking compound, tests were made with a 1/2 inch thread engagement length with no tightening torque.

4. Application of LOCTITE

A drop of LOCTITE was applied to each of 5 screws of each plate at the screw-plate junction after insertion allowing the liquid to penetrate into the space between the screw threads and plate. The LOCTITE was allowed to cure for at least three days at room temperature before tests were made. The sixth screw was inserted without any LOCTITE treatment and served as a control in all tests.

The following measurements and observations were made to evaluate the effectiveness of the locking compound.

a. Break-Loose Torque (T_B)

Sturdevant torque wrenches were used to determine the torque required to start rotation of the screw.

b. Prevailing Torque (T_P)

Sturdevant torque wrenches were used to determine the maximum torque required to rotate the screw one-half turn immediately after "break-loose".

c. "Walkout"

Visual observations for rotation tendencies of the screws were made during the vibration and shock testing. Time for complete "walkout" of the screws was measured from the start of the vibration cycles.

The test specimens were subjected to vibration and shock as described below. The test results abstracted from Frankford Arsenal Memorandum Report M61-20-1 entitled "A Preliminary Investigation of a Thread Locking Compound" are tabulated in Tables II to VII.

Table II. ORIGINAL CHARACTERISTICS

7075 Aluminum			85-5-5-5 Copper			1020 Steel		
	Torque (in.-lb)			Torque (in.-lb)			Torque (in.-lb)	
Condition	T_B	T_P	Condition	T_B	T_P	Condition	T_B	T_P
			LOCTITE H					
As fabricated	6	4	As fabricated	5	2	As fabricated	4	4
	8	6		6	4		4	4
	7	4		8	5		10	6
	10	5		11	7		9	4.5
	6	3		11	6		10.5	7.5
	6	4		4	3		8	4
	6	4		4	2		10	6
	8	6		6	2		9	5
	10	7		4	2		10	6
	4	2		10	5		5	5
	4	2		6	4		3	3
	6	3		7	4		6	4
	6	3		9	5		6	4
	7	3		10	5		11	5
	6	3		10	5		10	6
	8	3		10	5		10	5
	6	2		8	5		8	4
Average	6.7	3.8	Average	7.59	4.18	Average	7.8	4.9
σ	1.63	1.44		2.45	1.46		2.55	1.21
Black Anodize	12	5.5	Black Oxide	13	6	Cadmium Plate	5	4
	11	6		11	7		5	3
Average	11.5	5.75	Average	12	6.5	Average	5	3.5
			LOCTITE E					
As fabricated	17	12	As fabricated	20	16	As fabricated	25	18
	20	10		12	10		28	18
			LOCTITE C					
As fabricated	28	28	As fabricated	20	18	As fabricated	34	26
	14	14		32	20		40	25

Table III. EFFECT OF SHOCK AND VIBRATION
LOCTITE H

(7075 Aluminum)

Condition	Test	Torque (in.-lb) T_B	Torque (in.-lb) T_P	Walk-out	Remarks
As fabricated	4 G Vibration	6	4	0	Unbonded screws "walked-out" (1/2") in less than 2 minutes
		6	4	0	
		8	6	0	
		10	7	0	
		4	2	0	
		4	2	0	
		6	3	0	
		6	3	0	
	Average	6.5	3.9		
	Simultaneous Vibration 4 G and Shock 10 G	7	3	0	Unbonded screws "walked-out" (1/2") in less than 2 minutes
		6	3	0	
		8	3	0	
		6	2	0	
	Average	6.8	2.8		
	Alternate Vibration 4 G and Shock 1500 G	6	6	0	Unbonded screws "walked-out" in less than 40 seconds
		5	5	0	
		4	4	0	
		4.5	4.5	0	
	Average	4.9	4.9		
Black Anodize	Alternate Vibration 4 G and Shock 1500 G	3	2	0	Unbonded screws "walked-out" in 30-40 seconds. One bonded screw with T_B and T_P of 1 in. oz. "walked" approx. 30° on each of last 4 cycles of test.
		1	1	0	
		8	7	0	
		7	7	0	
		6	6	0	
		12	10	0	
		3.5	3	0	
	Average	5.8	5.1		

Table IV. EFFECT OF SHOCK AND VIBRATION
LOCTITE H

(85-5-5-5 Copper)

Condition	Test	Torque (in.-lb) T_B	Torque (in.-lb) T_P	Walk-out	Remarks
As fabricated	4 G Vibration	4	3	0	Unbonded screws "walked-out" in less than 2 minutes.
		4	2	0	
		6	2	0	
		4	2	0	
		10	5	0	
		6	4	0	
		7	4	0	
		9	5	0	
	Average	6.5	3.4		
	Simultaneous Vibration 4 G and Shock 10 G	10	5	0	Unbcnded screws "walked-out" in less 2 minutes.
		10	5	0	
		10	5	0	
		8	5	0	
	Average	9.5	5		
	Alternate Vibration 4 G and Shock 1500 G	8	4.5	0	Unbonded screws "walked-out" in 30-40 seconds.
		6	4.5	0	
		5	4	0	
		7	6.5	0	
		4	3	0	
		8	6	0	
		3	2	0	
		10	7	0	
	Average	6.4	4.7		
Black Oxide	Alternate Vibration 4 G and Shock 1500 G	9	5	0	Unbonded screws "walked-out" in 30-40 seconds.
		7	5	0	
		9	5	0	
		9.5	6	0	
		6	4	0	
		6	3.5	0	
		6	4	0	
		7	4	0	
	Average	7.4	4.6		

Table V. EFFECT OF SHOCK AND VIBRATION
LOCTITE H

(1020 Steel)

Condition	Test	Torque (in.-lb) T_B	T_P	Walk-out	Remarks
As fabricated	4 G Vibration	8	4	0	Unbonded screws "walked-out" in less than 2 minutes.
		10	6	0	
		9	5	0	
		10	6	0	
		5	3	0	
		3	3	0	
		6	4	0	
		6	4	0	
	Average	7.1	4.4		
	Simultaneous Vibration 4 G and Shock 10 G	11	5	0	Unbonded screws "walked-out" in less than 2 minutes.
		10	6	0	
		10	5	0	
		8	4	0	
	Average	9.5	5		
	Alternate Vibration 4 G and Shock 1500 G	10	8	0	Unbonded screws "walked-out" in 30-40 seconds.
		9	6.5	0	
		6	5	0	
		11	8	0	
		7	3.5	0	
		9	6	0	
		8	5.5	0	
		9	7	0	
	Average	8.6	6.2		
Cadmium Plate	Alternate Vibration 4 G and Shock 1500 G	5	3	0	Unbonded screws "walked-out" in 30-40 seconds.
		4	3	0	
		5	5	0	
		8.5	5	0	
		8	5	0	
		10	5	0	
		5	4	0	
	Average	6.5	4.3		

Table VI. EFFECT OF SHOCK AND VIBRATION
LOCTITE E AND C

LOCTITE Grade	Test	Aluminum* T_B	Aluminum* T_P	Copper* T_B	Copper* T_P	Steel* T_B	Steel* T_P
E	Vibration 4 G	16	12	20	16	28	22
		16	14	20	15	28	18
		17	13	22	15	26	18
		15	10	18	12	26	20
		18	12	12	8	22	16
		16	12	14	10	20	16
		14	8	11	8	28	16
		16	14	10	6	26	20
		16	11.9	15.8	11.2	26	18.2
C	Simultaneous Vibration 4 G and Shock 10 G	20	16	30	19	30	25
		18	14	30	18	38	34
		22	20	28	19	24	19
		24	21	32	20	35	22
		24	22	30	20	34	22
		20	19	32	19	34	29
		18	18	32	21	32	28
		32	32	26	18		
		22.2	20.2	30	19.2	31	25.5

*Untreated plates.

Table VII. EFFECT OF ENVIRONMENT EXPOSURE LOCTITE H*

(85-5-5-5 Copper)

	Torque Before Test		Torque After Test	
	T_B	T_P	T_B	T_P
	7	4	7	5
	6	3	7	5
			6	4
			6	4
			5	3
			5	3
			5	3
			9	7
Average	6.5	3.5	6.2	4.2

Note:*

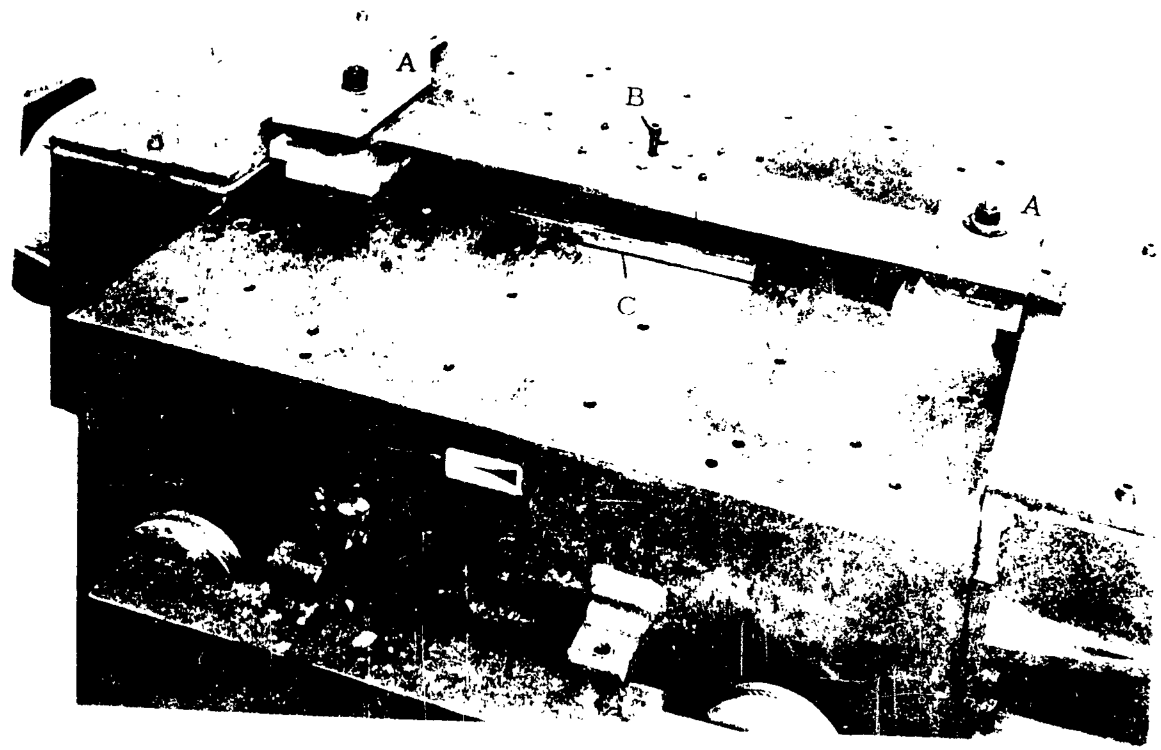
60 hrs; 95° F; 100% R.H.
Procedure 3 Test
Alternate Vibration 4 G and Shock 1500 G

1. Vibration Only

a. Procedure 1

The test plate, figure 1, was mounted on a 416 corrosion resisting steel bar 21" x 3" x 1/4" bolted to the vibrator table at A, figure 2, through 50 Durometer A rubber pads inserted between the bar and each of the bolt plates. The details of the assembly are shown in figure 3.

The vibration machine was adjusted so that one end of the table moved vertically (approx.) and the other end horizontally and perpendicular to the long dimension of the bar. Since these motions were at 90° time phase and the bar was free to flex vertically, the resultant motion of the test plate was somewhat elliptical, with a minor axis of 0.05" and a major axis of approximately 0.10" in a plane slightly tilted from the vertical.



A - Test Plate Fixture Assembly Mounting
B - Impact Screw
C - Impact Plate

Figure 2. Original Test Setup on Vibration Machine

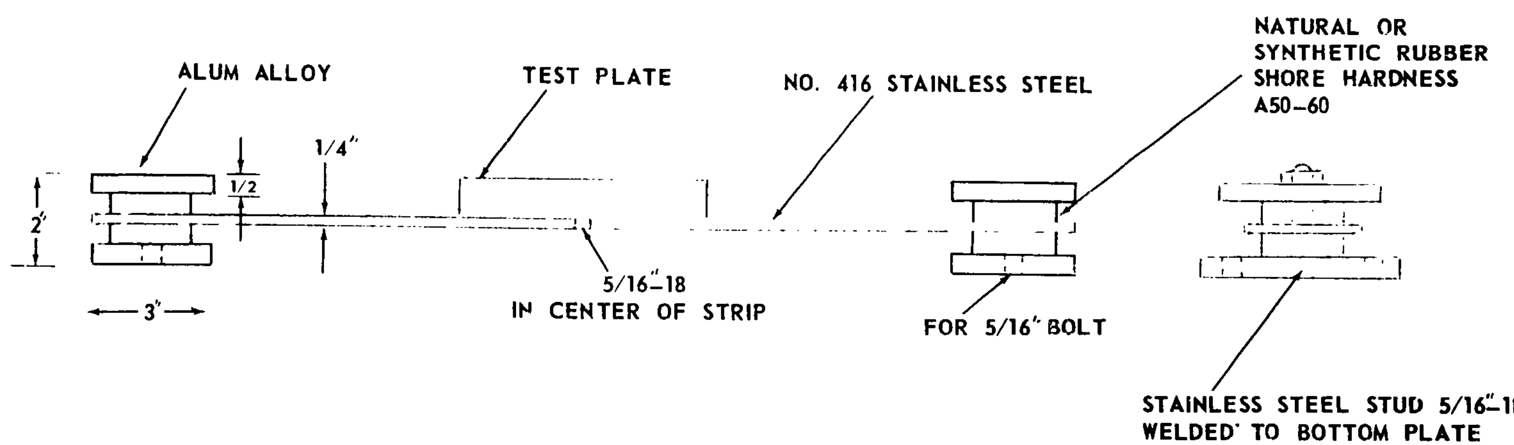


Figure 3. Threaded Fastener Locking Devices - Simultaneous Shock & Vibration Test Fixture

The applied vibration was programmed to vary continuously from 5 to 45 to 5 cps in 80 seconds periods. The plate acceleration as determined by an Endevco accelerometer was 4 G at 40 cps.

b. General Observation

No rotation of the unbonded screws was observed if vibration was restricted to linear displacement.

All unbonded screws invariably rotated when vibration resulted in circular or elliptical displacement. By reversal of displacement direction, the screws could be made to tighten or "walkout" within less than 2 minutes.

No rotation of the LOCTITE H and LOCTITE E bonded screws occurred.

2. Simultaneous Vibration and Shock

a. Procedure 2

The condition for this test was the same as for Procedure 1 except that the Rockwell C55 hardened steel bolt B (fig. 2) was adjusted to start contacting the impact plate C at approximately 28 cps (near resonance of the bar). This introduced a shock impulse of approximately 10 G on the basic vibration acceleration of 4 G.

b. General Observations

All unbonded screws invariably "walked-out" within less than 2 minutes when the elliptical displacement was in the proper direction.

No rotation of the LOCTITE H and LOCTITE C bonded screws was observable.

No rotation of the unbonded screws was observed when they were turned down to finger tightness in the plate.

3. Alternate Vibration and Shock

a. Procedure 3

Because the results obtained with Procedures 1 and 2 were inconclusive, a more severe test was improvised. The moment

of inertia of the screws was increased from 0.0127 x 10^{-4} lb-in.^{2} to 0.147 x 10^{-4} lb-in.^{2} by the addition of two flat washers and nut as shown in figure 1. The assembled test plate was mounted on the vibration bar as illustrated in figure 4.

The vibrator was adjusted so that the entire platform moved simultaneously in two directions — (1) horizontal and perpendicular to the screw axis, and (2) vertical and also perpendicular to the screw axis. The horizontal displacement was 90° out of time phase with respect to the vertical displacement. The table double amplitude displacement was 5/64". Due to the flexing of the vibration bar, the motion imparted to the test screws was elliptic in a plane perpendicular to the screw assembly axis about a center displaced from the screw axis by 0.075" (major) to 0.025" (minor) during the vibration cycle.

Shock impulses were applied with the superstructure shown in figure 5 by allowing the 2 pounds striking weight A attached to the 27" radius arm to fall from the 90° position to the plate support bracket C. The shock accelerations delivered to the test plate were determined with an Endevco Model 2213 accelerometer mounted on the test plate. The values obtained after filtering the accelerometer output through a 10-1000 cps band pass filter were of the order of 1500 G.

The test plate was subjected to 10 cycles of alternate vibration and shock. Each cycle consisted of 5 minutes of vibration (5 to 45 to 5 cps in 75 seconds) followed by 10 pendulum delivered shocks.

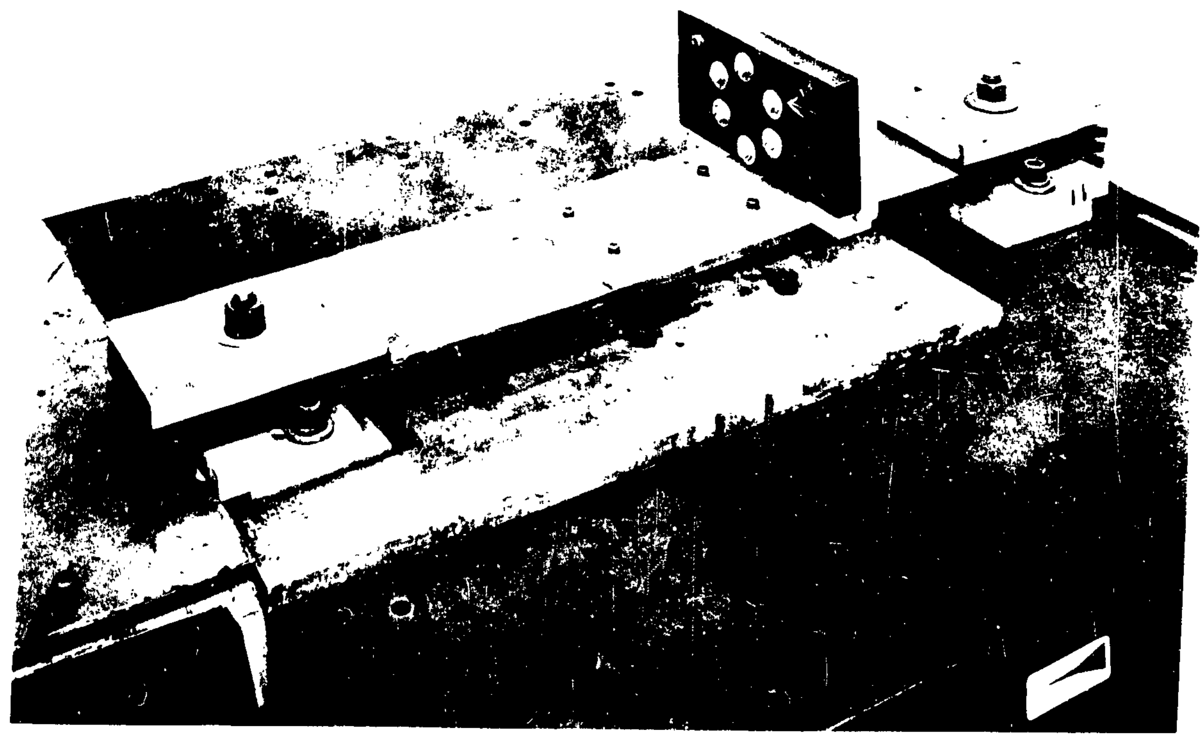
b. General Observations

All unbonded screws invariably "walked-out" within 30-40 seconds when the elliptical displacement was in the right direction.

An unbonded screw turned down with a tightening torque of 2 in.-lb "walked-out" under these test conditions.

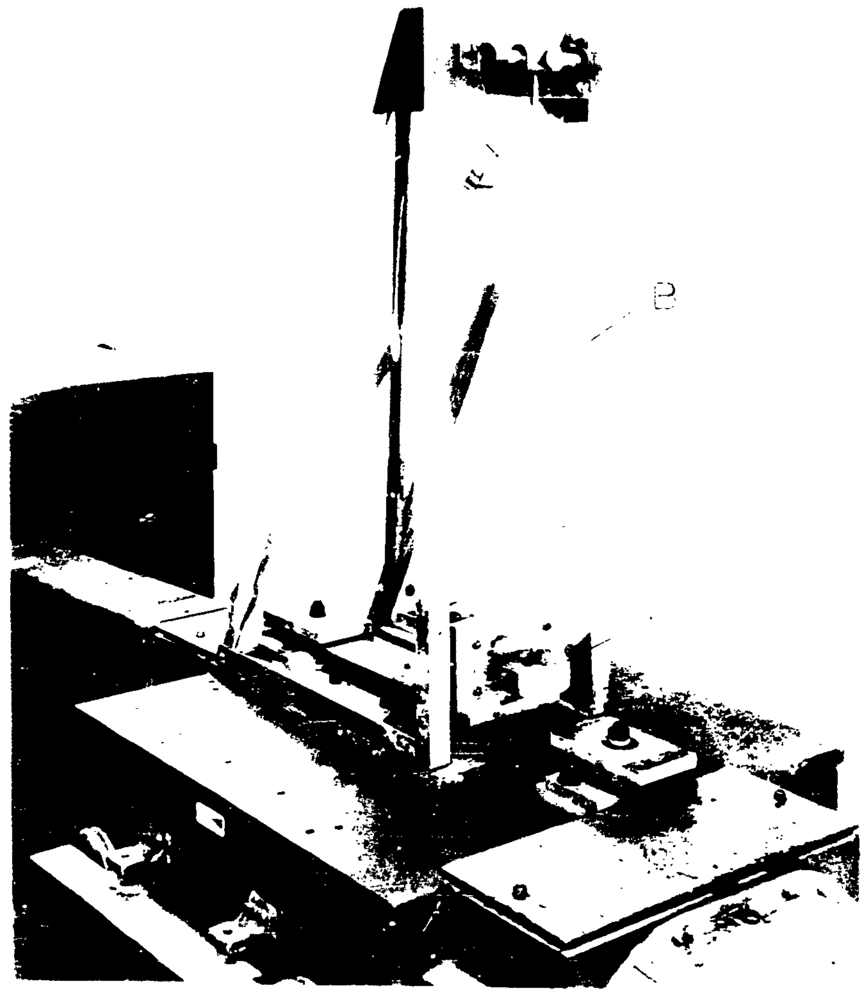
One bonded screw exhibiting a prevailing torque of 1 in.-oz rotated approximately 30 degrees on each of the last 4 test cycles. No other LOCTITE H bonded screws showed any tendency to "walk". Exposure for 60 hours at 100° R.H. at 95° F indicated no deteriorating effect.

Tests made with Nylok (nylon insert) screws showed no tendency to "walk" with prevailing torques ranging from 3 in.-oz to 2 in.-lb.



Procedure 3

Figure 4. Threaded Fastener Locking Devices - Alternate Shock and Vibration Test Setup



Procedure 3

A - Weight
B - Pendulum Radius Arm
C - Plate Support Bracket

Figure 5. Threaded Fastener Locking Devices - Alternate Shock and Vibration Test with Pendulum Impact Device in Place

A summary of the results is given below.

1. Original Characteristics

A plot of the relation between the breakloose and prevailing torques is shown in figure 6. The considerable variability of the data may be attributed to two factors – (a) the variability of the properties of the cured material and (b) the nonuniformity of the penetration of the material as applied. No pattern appears which would indicate that any differences exist which may be attributed to the material surfaces involved in this investigation. When examined after the tests, it was discovered that the LOCTITE material covered only 8 to 11 screw threads of the 16 thread engagement. In no case was complete penetration observed. The prevailing torque (T_P) can be calculated approximately from the formula[5]

$$T_P = KD^2L$$

where

K = 300-700 for LOCTITE H

700-1600 for LOCTITE E

1200-2800 for LOCTITE C

D = Mean diameter = 0.183 inch

L = Bonded length (8-11 threads) = 0.25"-0.34"

From this relationship, the following calculated values for T_P were obtained.

LOCTITE	Prevailing Torque - in.-lb T_P Calculated, 8 Threads	Calculated, 11 Threads	Actual
H	2.5-5.9	3.3-7.7	2-8
E	5.9-13.4	7.7-18.	10-18
C	13.2-23.5	13.2-30.8	14-28

The calculated values agree very well with the range of values observed.

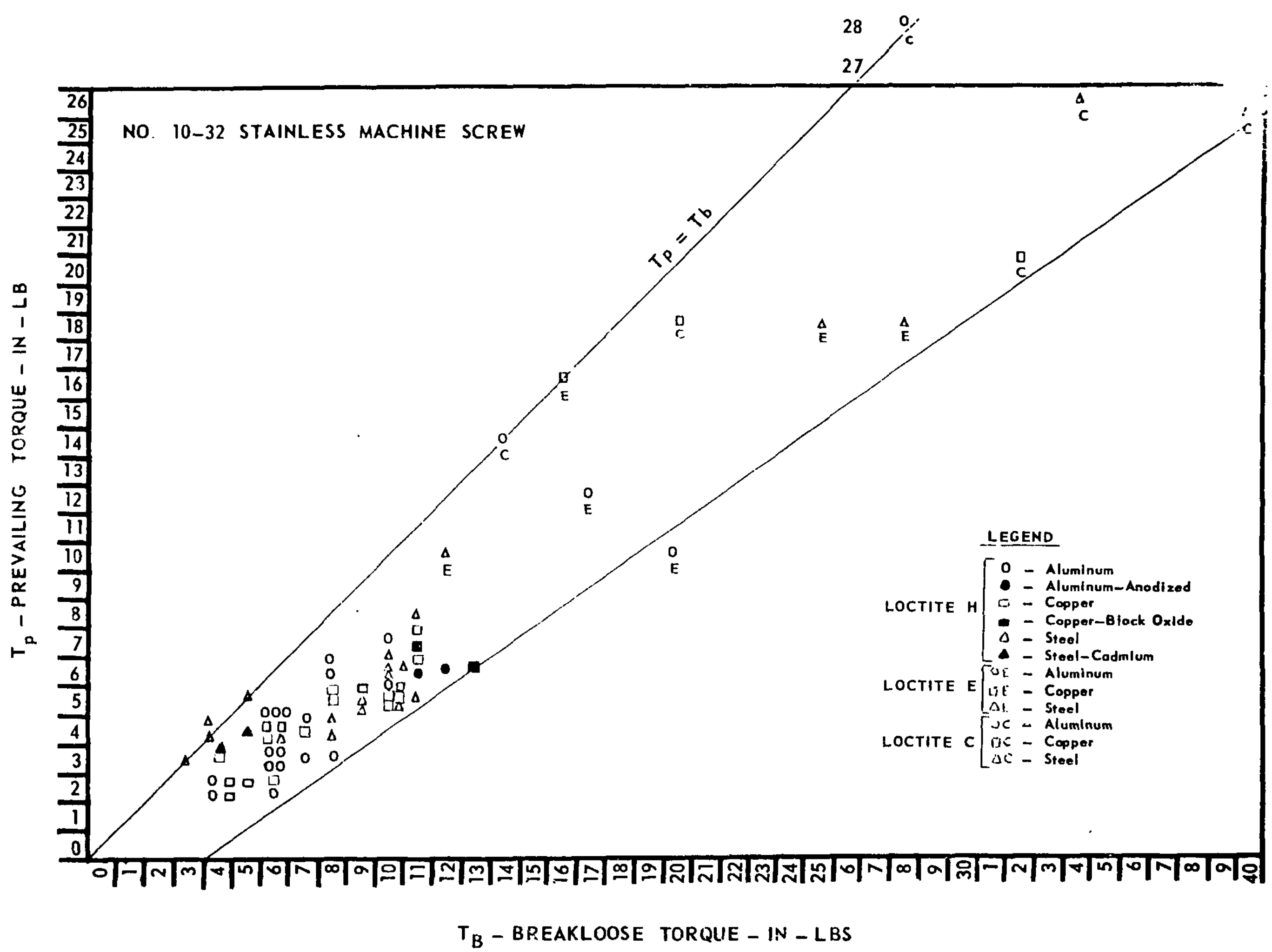


Figure 6. Threaded Fastener Locking Devices - Screw Locking Compound LOCTITE - Original Characteristics

2. Shock and Vibration Effects

The breakloose torques and corresponding prevailing torques measured after subjection to the shock and vibration tests are shown graphically in figures 7, 8, and 9. Here again the data is quite variable. These data all lie within the same maximum and minimum limit lines established by the original test data.

However, practically all of the test data obtained with the aluminum plates under Procedure 3 lie on the $T_P = T_B$ line. This characteristic is not prevalent with the untested or the low shock test conditions. This may be interpreted as a loss of bonding caused by the high shock conditions. The data cannot show if a loss in breakloose torque which should accompany this behavior actually occurred. The data obtained from all of the other tests do not show this characteristic.

Except for one test, the break and prevailing torques were sufficiently high to prevent "walkout". The one exception, possessing a prevailing torque of 1 in.-oz rotated 30 degrees during each of the last 4 procedure 3 vibration shock cycles.

Exposure for 60 hours to 100% R.H. at 95° F appears to have had no effect on the T_P and T_B characteristics of LOCTITE H.

DISCUSSION

None of the test procedures used in this investigation were severe enough to cause loosening and "walkout" of bonded screws even though prevailing torques as low as 1 in.-lb were involved.

In this investigation, two distinct characteristics of the locking compound must be considered.

1. The first condition is the environment which would disrupt the screw-LOCTITE-base metal bond system.

Loosening of threaded fasteners is produced by simple fluctuation of tension. Goodier and Sweeney[8] experimentally demonstrated the following theory. "When a bolt (with nut) is loaded in tension, the diameter contracts elastically according to Poisson's ratio. The nut expands because it is compressed against its seat. During any increase of load, the bolt thread is moving radially inward and the nut thread radially outward. Circumferential friction is required to counteract

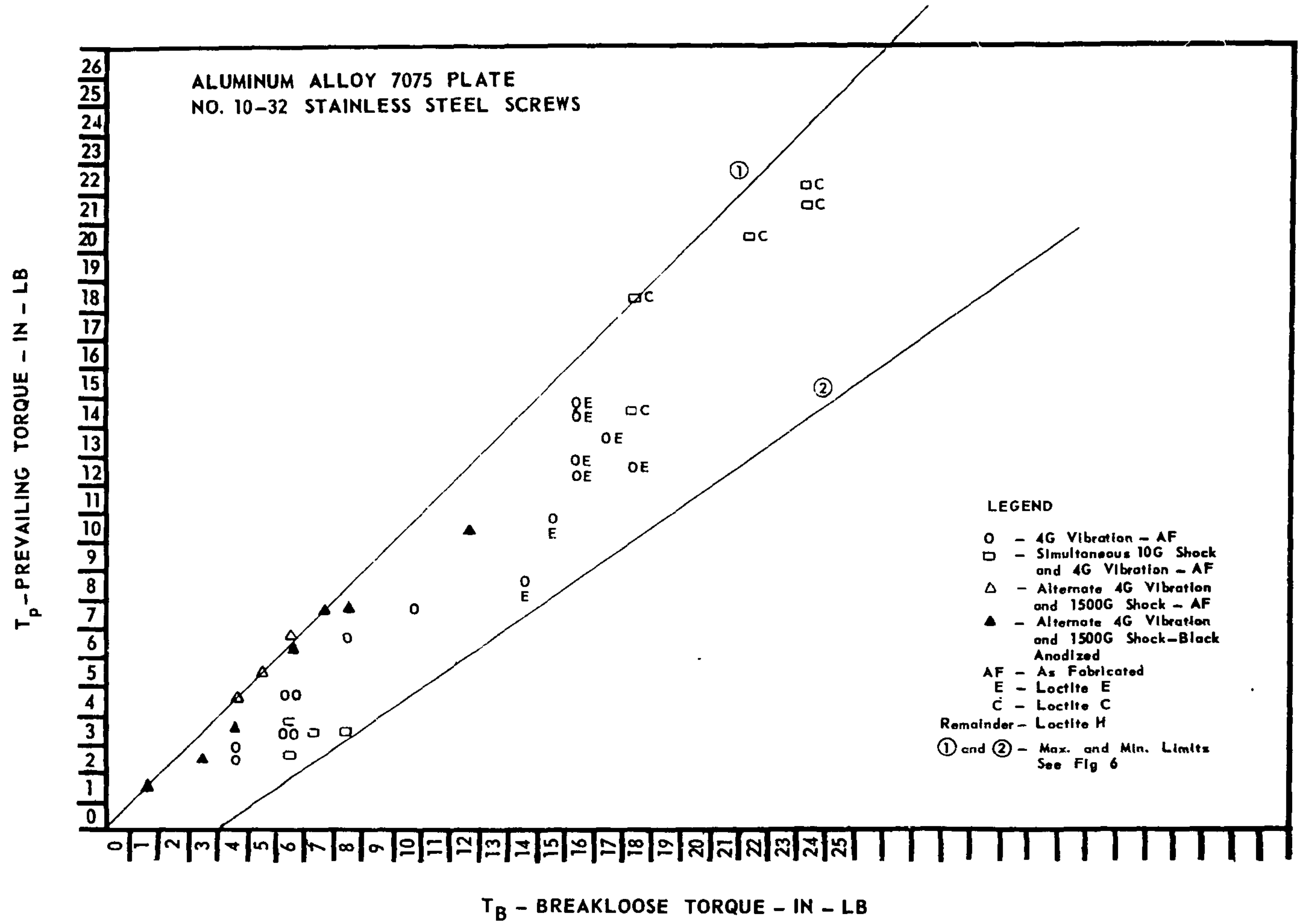


Figure 7. Threaded Fastener Locking Devices - Screw Locking Compound LOCTITE - Effect of Shock and Vibration

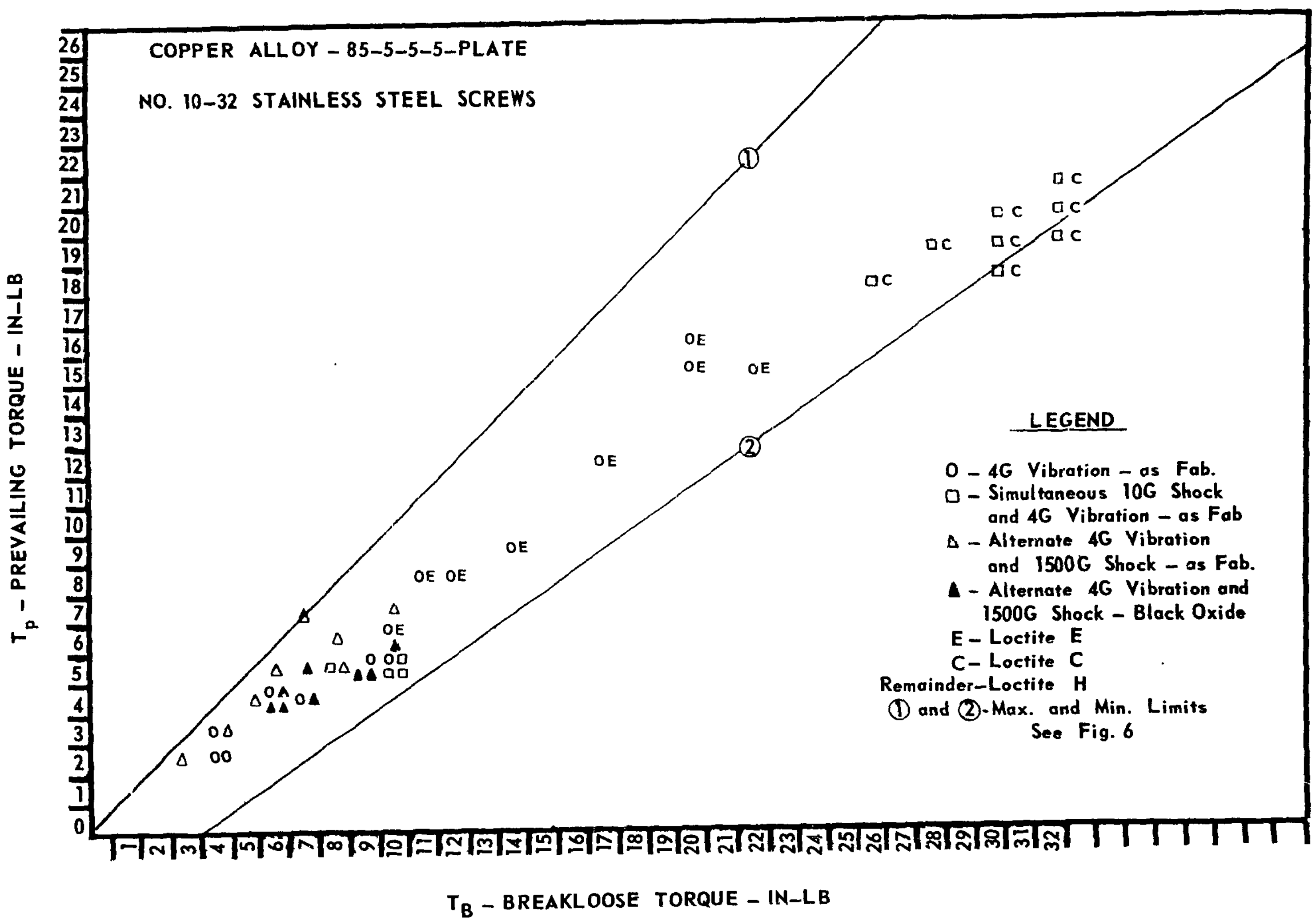


Figure 8. Threaded Fastener Locking Devices - Screw Locking Compound LOCTITE - Effect of Shock and Vibration

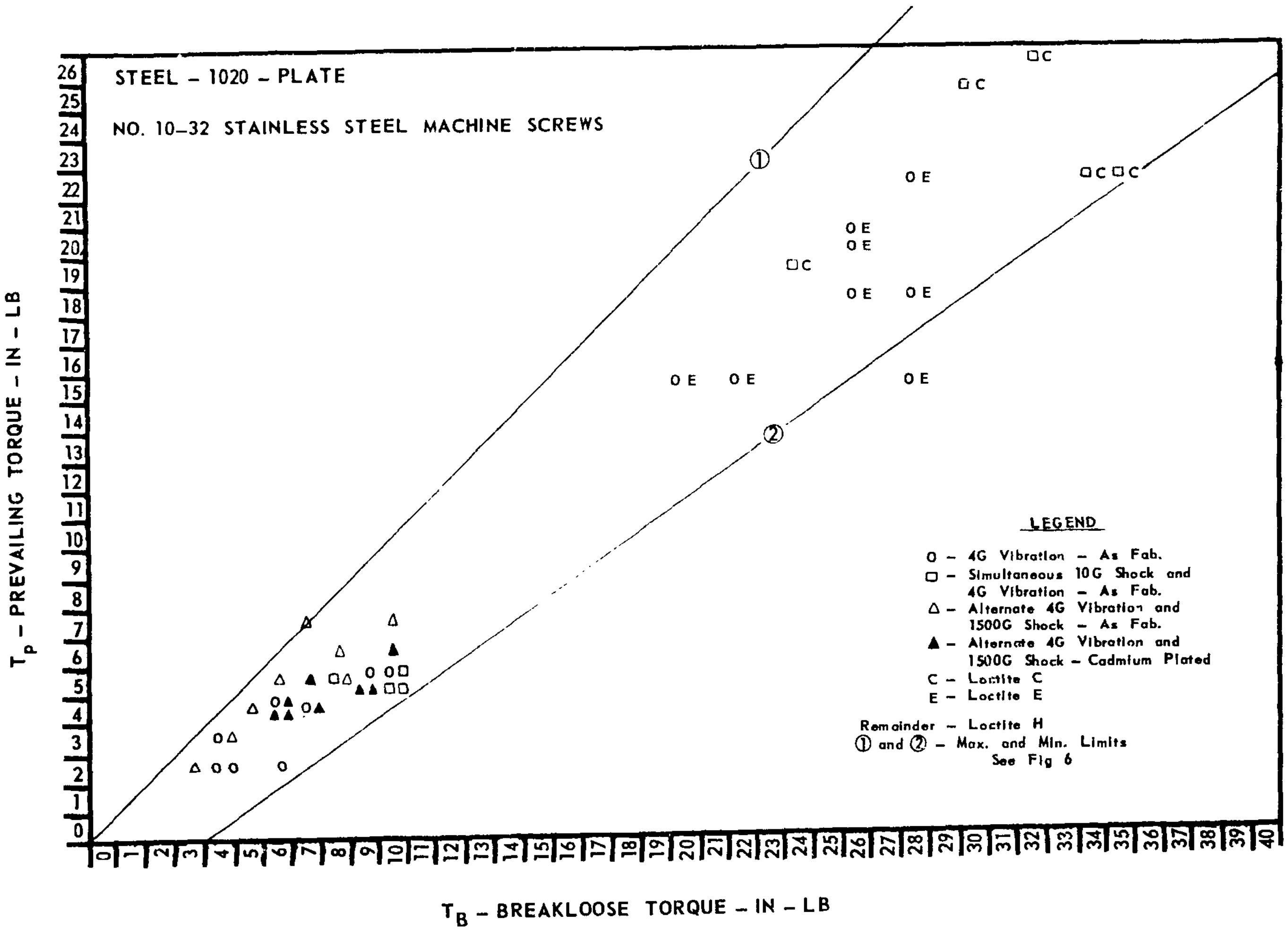


Figure 9. Threaded Fastener Locking Devices - Screw Locking Compound LOCTITE - Effect of Shock and Vibration

the loosening torque of the normal components of thread pressure. While the load is changing, therefore, the nut and bolt act as a reversible screw mechanism. The pull in the bolt causes rotation of the nut" if the resultant torque exceeds the counteracting friction torque.

When a shock impulse is applied in the direction of the screw axis, a force is created between the screw threads and the base metal threads due to the inertia of the screw assembly. This, according to the theory, would create a circumferential force which may exceed the bond strength of the locking compound. With lock washers and similar holding devices, no prevailing torque exists after the bolting tension has been released. The screws will then be "loose". With locking compound, the prevailing torque will exist as long as the screw is engaged with the base plate. This would account for equality between T_P and T_B after the high shock tests. Loosening will then be progressive rather than sudden.

2. The second condition is the vibrational environment which would cause "walkout" after disruption of the bond or even cause both bond failure and "walkout".

A study was made to analyze the test conditions to determine the existence and magnitude of screw turning torques generated by the circular orbit of the screw around the vibration displacement center axis.

In figure 10 is shown an instantaneous picture of the screw assembly and its relation to the displacement center.

Figure 11 is a diagram representing the essential features of the vibrating screw at some instantaneous position A at a displacement angle θ. The velocity V_o of any point P on the radius of gyration circle, which can be considered to contain the mass of the screw assembly, will be

$$V_o = 2\pi f r_o \tag{1}$$

Where f = frequency of vibration or rotation, and

$$V_s = V_o \cos \beta \tag{2}$$

From triangle AOP

$$k^2 = r_d^2 + r_o^2 - 2r_d r_o \cos(\phi - \theta)$$

and

$$r_d^2 = r_o^2 + k^2 - 2kr_o \cos \beta$$

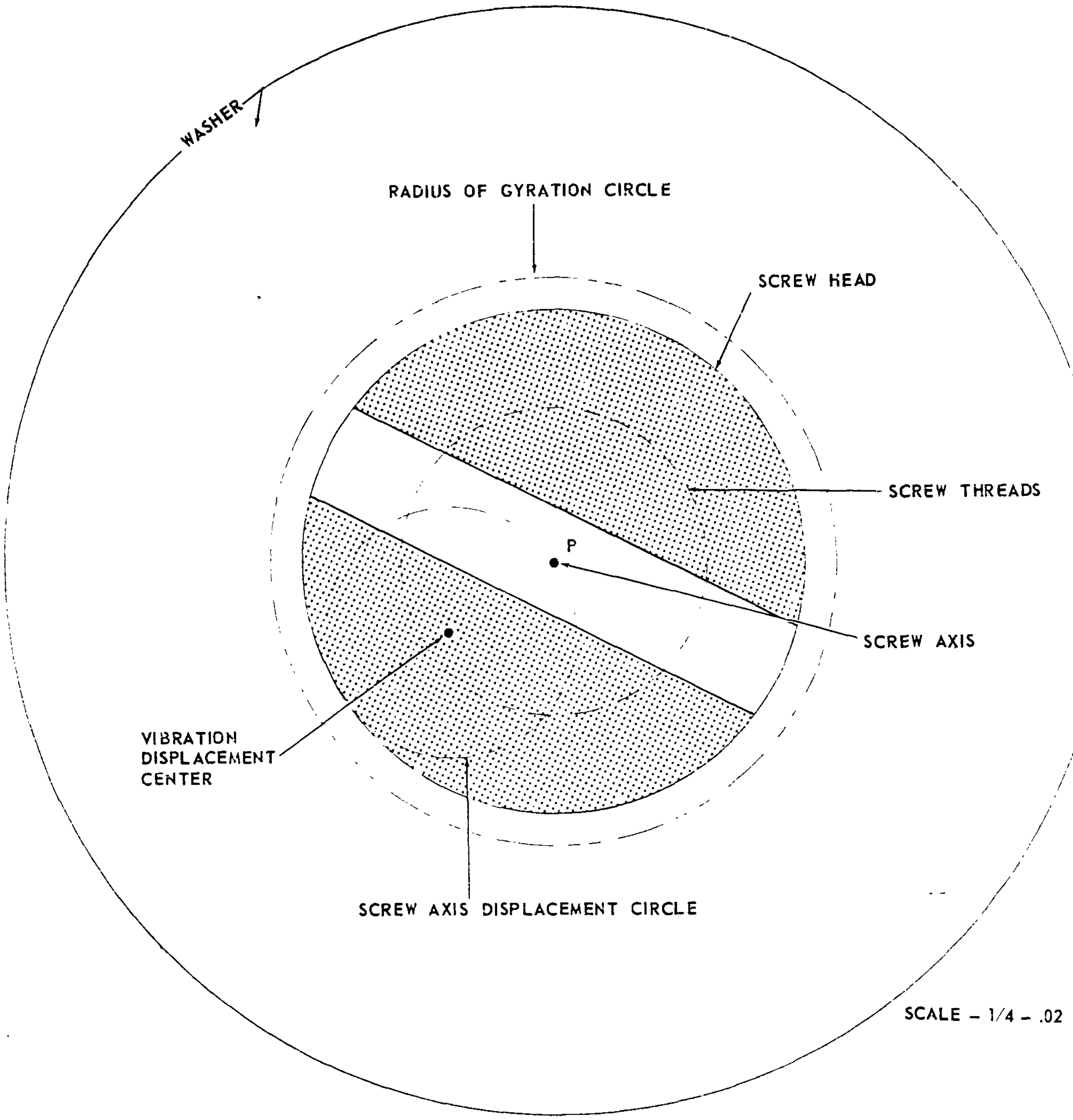


Figure 10. Threaded Fastener Locking Devices - Screw Assembly Relative to Vibration Orbit

r_d – Displacement circle radius
k – Radius of gyration (screw)
r_o – Distance between any point p and center of displacement axis
C_1 – Displacement path circle
C_2 – k circle around screw center axis A
V_o – Tangential velocity of P around O
V_s – Component of Vo tangential to screw around A

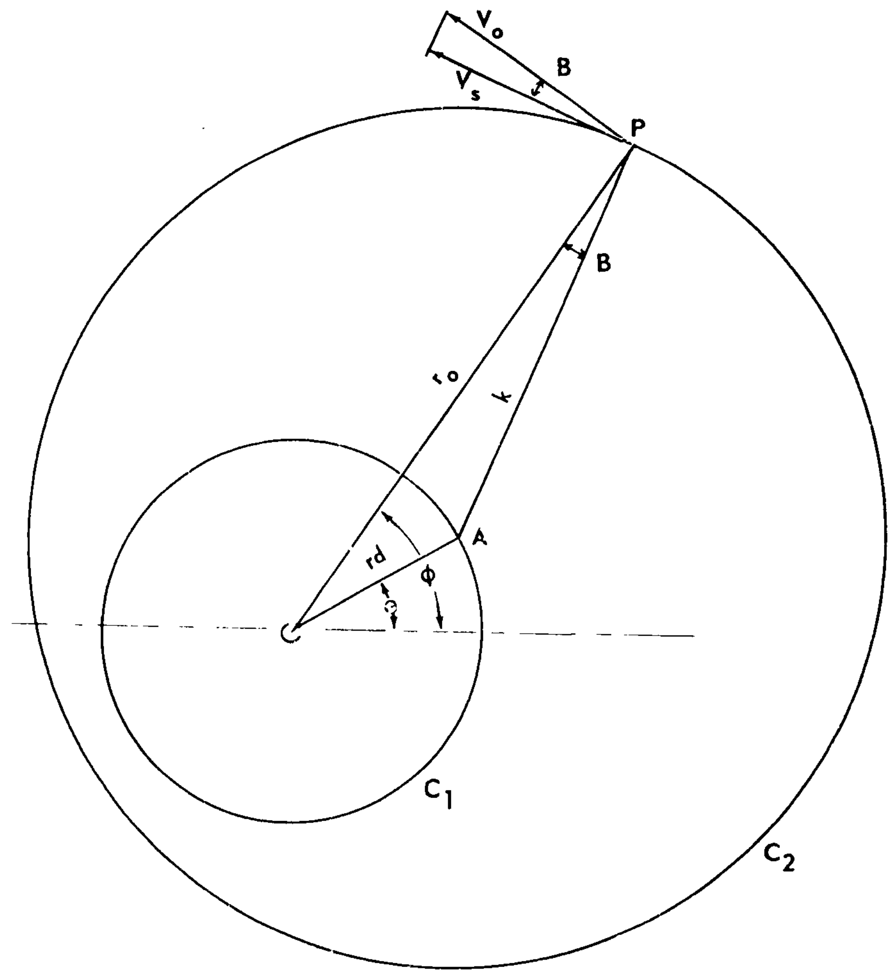


Figure 11. Threaded Fastener Locking Devices - Diagram of Vibrating Screw Relative to Vibration Axis

Solving for r_o

$$\cos\beta = \frac{k^2 + r_o^2 - r_d^2}{2kr_o}$$

and $$r_o = k\left[R\cos\gamma + \sqrt{1 - R^2\sin^2\gamma}\right] \tag{3}$$

where $$R = \frac{r_d}{k}$$

and $$\gamma = \phi - \theta$$

substituting in (2) for the condition $R < 0.5$ and neglecting all terms containing powers of R above 3, we obtain

$$V_s = \pi fk\left[R^2\cos 2\gamma + 2 - R^2 + 2R\cos\gamma - R^3\cos\gamma\sin^2\gamma\right]$$

and differentiating V_s with respect to γ and dividing $(\frac{dV_s}{d\gamma})^2$ by k,

we obtain the acceleration of point P with respect to A.

$$a_p = \pi^2 f^2 k\left[-\frac{8}{3}R^3(2 + R^3)\sin^3\gamma - 6R^4(2 + R^2)(\frac{3\gamma}{8} - \frac{\sin 2\gamma}{4} + \frac{\sin 4\gamma}{32})\right.$$

$$+ (4R^2 + 4R^4 + R^6)(\frac{\gamma}{2} - \frac{\sin 2\gamma}{4}) - 2R^4(\frac{1}{4}\sin 4\gamma - \gamma)$$

$$\left. + 9R^6\sin^6\gamma + \frac{24R^5}{5}\sin^5\gamma\right]$$

The total torque corresponding to this acceleration is the summation of the torques T_P at each point P around A.

$$\Sigma T_P = \sum_{\gamma = o}^{\gamma = 2\pi} Ia_p$$

By integration, expansion and neglecting all terms containing R raised to powers greater than 3, we obtain the total torque developed at any moment

$$T = 496 f^2 I \frac{r_d^2}{k}$$

For the general condition where the screw axis moves along an elliptical orbit around the displacement center

$$T = \frac{496 f^2 I}{k} \cdot \frac{b^2 c^2}{b^2 + (c^2 - b^2) \sin^2 \theta}$$

where

c = semiminor orbit axis

b = semimajor orbit axis

θ = displacement angle (see fig. 11)

Values of T for the parameters involved in the tests were calculated for two frequencies and are shown plotted as a function of the displacement angle in figure 12. These parameters are

$I = 0.147 \times 10^{-4}$ lb-in.^{2}

f = 25 and 45 cps

k = 0.173 in.

c = 0.025 in.

b = 0.075 in.

For the case of the circular displacement orbit $c = b$ and

$$T = 496 \frac{f^2 I}{k} r_c^2$$

where r_c = radius of the displacement circle.

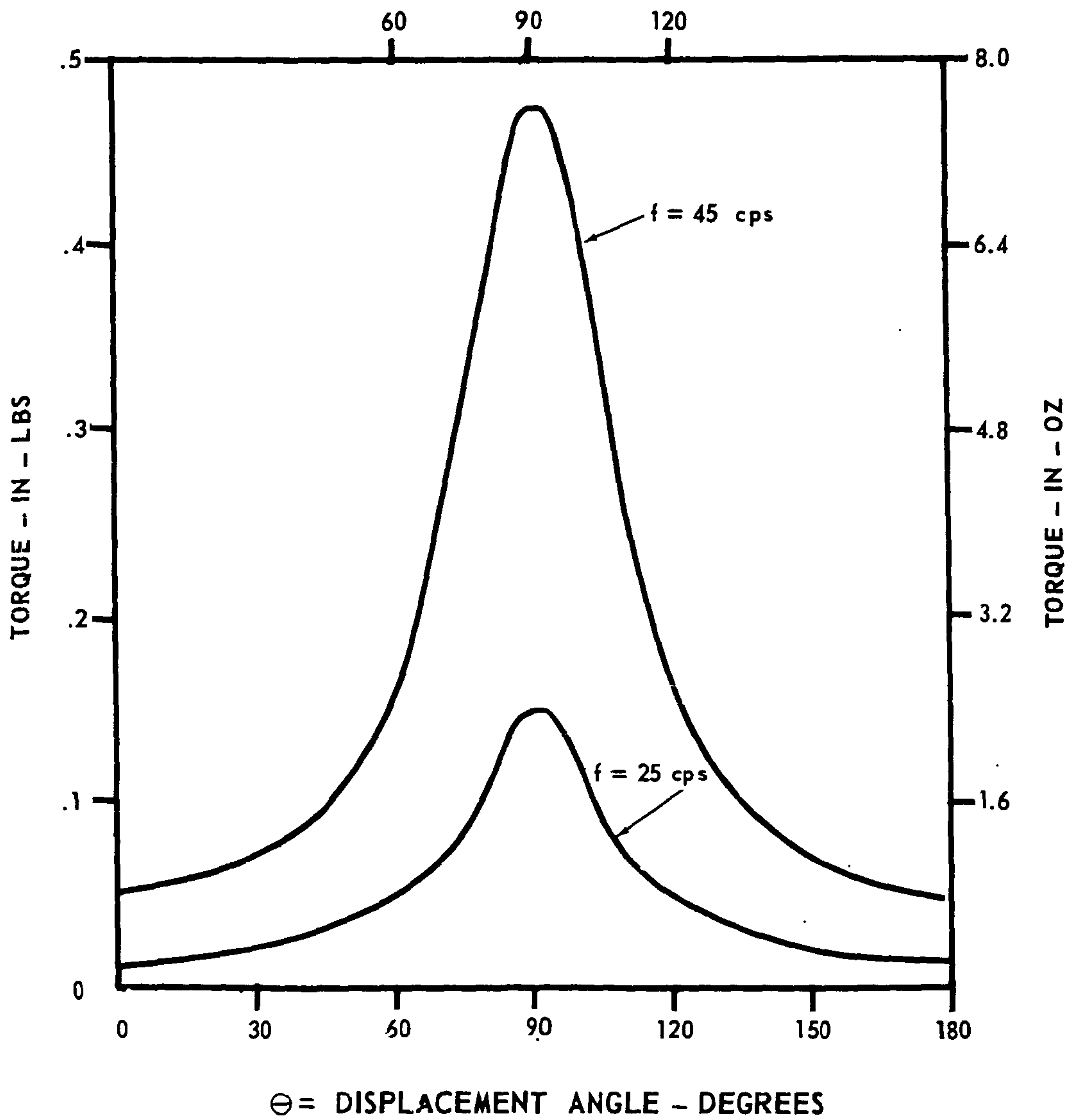


Figure 12. Threaded Fastener Locking Devices - Developed "Walk-out" Torque as a Function of the Vibration Displacement Angle Position of Screw

From this data, it is observed that the maximum momentary "walkout" torque developed in the tests was 0.48 in.-lb at the 45 cps part of the vibration cycle. This is considerably less than the prevailing torque characteristics exhibited by the test specimens. This would explain the absence of "walkout" in the tests of the treated screws and the unfailing "walkout" of the untreated screws.

On the basis of the above formula, it would appear that a torque of 50 in.-lb could be developed by raising the vibration frequency to 450 cps. This would be more than ample to cause "walkout".

CONCLUSIONS

The weakest grade of LOCTITE - Grade H - performs as well as MIL-V-173 Varnish, MIL-S-11031 Sealing Compound and screws with nylon inserts under the combined shock (1500 G – 1000 cps) and vibration (4 G – 5-45-5 cps) conditions investigated.

Only partial penetration of LOCTITE by capillary action is obtained when applied after screw insertion. In order to insure maximum reliability, the compound should be applied to the screw threads before insertion into the tapped holes.

Given the actual bonding area, the minimum breakloose and prevailing torques can be computed by using the following formulae

$$T_P = KD^2L \text{ inch pounds}$$

and

$$T_B = 1.4\,(T_P + 3) \text{ inch pounds}$$

where

D = pitch diameter of the threaded fastener

L = bond length

K = 300 for LOCTITE H

700 for LOCTITE E

1200 for LOCTITE C

3000 for LOCTITES A or D

The compound showed no sign of aging during the period of this investigation. After 12 months, under uncontrolled room conditions, no change in the capabilities of LOCTITE could be observed.

The compound showed no evidence of significant "set up" within the first 30 minutes thus allowing ample time for adjustment.

The test conditions are not sufficiently severe to quantitatively determine the vibration "walkout" limits of threaded fasteners. On the basis of an analysis, it appears that the design of test equipment to accomplish this is feasible. From this analysis, it has been determined that the "walkout" torque developed on a screw under elliptical vibration is

$$T = \frac{496 f^2 I}{k} \cdot \frac{b^2 c^2}{b^2 + (c^2 - b^2) \sin^2 \theta} \quad \text{in.-lb}$$

where

f = vibration frequency, cps

I = moment of inertia about the screw axis, lb-in.^{2}

k = radius of gyration about the screw axis, in.

b = semimajor vibration amplitude, in.

c = semiminor vibration amplitude, in.

θ = displacement angle

Thus the torque may be adjusted by variation in frequency, variation in vibration amplitude, and variations of I and k of the screw. On the basis of this relationship, it was determined that the effective torques developed during these tests were well under 0.5 inch pound which is considerably below the prevailing torques measured.

RECOMMENDATIONS

LOCTITE Grades A to H can be used for antivibration and shock locking threaded fasteners in lieu of the present "dab" materials MIL-V-173 varnish and MIL-S-11031 sealing compounds. These should not be relied upon for fastening under high frequency, high amplitude vibration conditions.

LOCTITE Grades A, C, and H will fulfill most of the design requirements. These are adequately covered under Military Specification MIL-S-40083(ORD), although a vibration performance test requirement would be desirable.

When used, these materials should be applied to the threaded fasteners prior to insertion. Application after insertion is unreliable and should not be encouraged.

There is a need for an adequate means for evaluating locking methods. It is recommended that a program be initiated to verify the relationship between "walkout" torque and circular vibration frequency and amplitude developed in this report.

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